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AGILITY, GNOSIS, AND GRAPHAESTHESIA FOR THE TOES AND FINGERS IN CHILDREN: NORMATIVE DATA (AGES 7–14 YEARS)

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The differential representation of the toes/feet and fingers/hands along the medial and lateral surfaces of the cerebral cortices, respectively, may have diagnostic utility. Normative data for errors for toe and finger graphaesthesia and gnosis, as well as foot and finger agility, were collected for 86 children (ages 7 to 14). The fingers were more agile than the feet, and the right side of the body was more agile than the left side, regardless of age. A marked improvement in toe gnosis, but not in finger gnosis occurred in children after 11–12 years of age. A statistically significant interaction between laterality and gender was due to the greater numbers of errors for both toe and finger gnosis, displayed by girls for the left sides of their bodies compared to their right sides. This discrepancy was not significant for boys.

Keywords child, finger gnosis, ontogeny, sex differences, toe gnosis

Modern, clinical neuropsychological assessments employ a matrix of quantitative data, by which the functioning of specific regions of the cerebrum can be inferred. However, even a cursory inspection of the general and specific cerebral regions that are indexed by the

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most frequently employed neuropsychological procedures (Kolb & Whishaw, 1990) reveal a conspicuous paucity of measures for the medial surfaces of the cerebral hemispheres. If the primary assumptions of clinical neurology and the results of Penfield and Rasmussen (1950) are generalizable, then the efferent (motor) neurons for the feet should be represented within the medial frontal cortices, while afferent information from the feet (toes) should be represented within the medial parietal cortices. Quantitative measurements of foot agility, toe gnosis, and toe graphaesthesia could be valuable inferences of the functional and differential integrity of the medial prefrontal and paracentral lobules during ontogeny.

Neuropsychological indices for the ontogenetic development of the paracentral parietal lobes would allow more precise inferences of the integrity of this region subsequent to traumatic brain injury in children. Because the paracentral lobules are serviced by the most distal branches of the anterior cerebral artery (Nolte, 1988), one would expect these neurons to be particularly sensitive to ischemia and subclinical diaschisis. From a theoretical perspective, the existence of any differential maturation of the toes and feet, relative to the fingers and hands as a function of age, may facilitate understanding of the neurocognitive processes that accompany the clumsiness and awkward ambulation of early adolescence.

Although normative data for finger gnosis and graphaesthesia in children have been collected and published by Knights and Norwood (1980), there have been no studies, to our knowledge, that have determined ontogenetic (age-dependent) measures for gnosis and graphaesthesia of the toes. We, Richards and Persinger (1992), have collected normative data for toe gnosis and graphaesthesia for adults. The ratios of errors for the toes, relative to the fingers was about 4:1 for both the ability to (accurately) identify digits (toe gnosis), and to recognize numbers (3, 4, 5, or 6) written on the pads of the digits (toe graphaesthesia) with a stylus. Our results were compatible with Singh (1990) and Fein (1987), who showed more frequent and systematic misidentification of the toes compared to the fingers. The present study investigated the ontogenetic pattern of: (1) motor speed and agility of the fingers and the feet, and (2) errors for gnosis and graphaesthesia for the fingers and the toes.

MATERIALS AND METHODS

Subjects

Eighty-six students (36 males and 50 females), 7 to 14 years of age, participated in this study. The numbers of subjects per age group ranged from 7 to 17. Subjects were obtained on a voluntary basis from five schools in the Sudbury, Ontario, region; written permission from their parents was required. Subjects had no known neurological problems. Seventy-seven percent of the sample was right hand dominant, 10% was left hand dominant, and 2% was ambidextrous according to the Reitan-Klove Lateral Dominance Exam (Reitan & Wolfson, 1985).

Procedure

Each subject was tested individually during one session, which lasted approximately 45 min. The subject was told that the study was concerned with "how fast you could tap your fingers and your feet" and "how well you could identify your fingers and your toes, as well as guess numbers drawn on your fingers and toes." The amount of time per week that each child reportedly played with nintendo, computers, piano, organ, guitar, other instruments, and sports was recorded.

A maximum level of performance was encouraged for all measures. The motor indices (finger oscillation task followed by foot tap) were administered first. The finger tapping task employed the standard (adult) manual tapper from the Reitan Neuropsychology Lab (Tucson, Arizona, Model #727235 001). Details of the procedure and the instructions are described in Reitan and Wolfson (1985). The foot tap device was comprised of a pedal mounted on a board, Model #32738, which was placed on the floor, attached to an electronic counter, Model #58022, manufactured by Lafayette Instruments. Details of the procedure and instructions were adapted from Knights and Norwood (1980).

For the sensory indices, the order of administration for fingers and toes was counterbalanced to control for practice effects. The gnosis tasks were administered, followed by the number writing

(graphaesthesia) tasks. Details of the tactile finger recognition and finger-tip number writing procedure and instructions can be found in Reitan and Wolfson (1985).

Toe gnosis and toe graphaesthesia were tested by applying the finger procedures to the toes (Richards & Persinger, 1992). To test toe gnosis, the subject was asked to place the foot (no socks) flat on the ground. Each toe was given a number in descending order, with 1 for the big toe and 5 for the little toe. The subject was then instructed to keep his or her eyes closed. To insure the subject had associated the correct number with each toe, and in order to determine the appropriate stimulus intensity, each toe was touched sequentially (all subjects learned the association). A light touch (index finger of examiner) was then applied to each toe immediately caudal to the origin of the toenail. The stimulus was given in random order with adjacent toes never being tested in succession; each toe was touched a total of four times. The numbers of errors for the right and left foot (maximum of 20 for each foot) were recorded.

For the toe graphaesthesia task, the subject, while sitting, was asked to place each foot (no sock) on a chair with the sole of the foot facing the examiner. The symbols to be drawn, an X or an O for subjects ages 7 and 8; the numbers 3, 4, 5, or 6 for subjects ages 9 to 14, were drawn on the dorsal surface of the foot for purposes of demonstration. The subject was required to close both eyes and to identify the symbol (number or X/O) drawn on the toe pads. The symbols were administered in the same order employed to assess finger graphaesthesia. The symbols were written clearly and distinctly with a steady pressure, using a stylus (ballpoint pen without ink). A different toe was used for each trial beginning with the big toe and continuing consecutively from the adjacent toe to the baby toe. The 9- to 14-year-old subjects, who received the numerical stimuli, were reminded that since the examiner was facing them, the numbers written would be upside down to them. The total numbers of errors for the right and left foot (maximum of 20 for each foot) were recorded.

At the end of the testing session, the child's height and weight were recorded. Height was measured in feet and inches using a wall height chart manufactured by Galt Toys. Weight was measured in pounds using a household scale manufactured by Counsellor Model

#SK-4067. Only one subject, a 7-year-old boy, refused to participate in the toe measures; the remaining tasks were still administered to him. There were no other difficulties with cooperation, distraction, or interruption during the testing periods.

Statistical Analyses

All statistical analyses involved SPSS software on a Vax 4000 computer. The primary design for the investigation of a differential rate of development between the fingers and the feet/toes was a four-way analysis of variance (MANOVA, SPSS) with two levels repeated (finger and foot/toes; right versus left side of the body) and two nonrepeated (age and sex). Post hoc and correlational analyses were also completed. To facilitate an understanding of the results, the subjects were collapsed into four age groups (7–8 years, 9–10 years, 11–12 years, and 13–14 years); employment of each age group singly, i.e., 8 groups, did not demonstrate any additional or different results.

RESULTS

The means and standard deviations for height and weight, the numbers of finger taps and foot taps per 10 s for the dominant and nondominant limbs, and the total numbers (left and right limb) of errors for the finger gnosis, toe gnosis, finger graphaesthesia, and toe graphaesthesia are shown in Table 1 for each of the four age groups (7–8, 9–10, 11–12, 13–14). Because there were statistically significant differences between all of the measures for the groups, the strengths of the effects (as inferred by the eta values) are included, rather than traditional *p*-values. Neither the effect size nor the magnitudes of the F values changed appreciably when only right handers were included in these analyses.

In order to measure possible contributions to these differences from sources other than age, separate analyses of variance, covarying for height and weight, were performed. The results are presented in Table 2. The magnitudes of the statistical significance of the age group differences before and after covariance are indicated by the asterisks.

TABLE 1. Means and standard deviations for the right and left limb combined for motor (finger and foot tap) and sensory (total errors for finger and toe gnosis and graphaesthesia), and height (in inches) and weight (in pounds) as a function of four age groups

	7–8 yr (n = 21)		*9–10 yr (n = 26)*		*11–12 yr (n = 15)*		*13–14 yr (n = 24)*		
Variable	*M*	*SD*	*N*	*SD*	*N*	*SD*	*N*	*SD*	*eta*
Finger tap	62.9	7.3	80.6	8.7	90.2	7.5	93.0	8.9	0.82
Foot tap	50.7	8.9	63.9	11.8	70.1	11.8	82.8	11.3	0.74
Finger gnosis	3.2	2.3	2.4	2.6	1.4	2.5	1.0	1.6	0.34
Toe gnosis	14.5	4.4	12.0	3.5	8.1	3.9	10.1	4.7	0.47
Finger graph	1.3	2.2	5.8	4.2	2.0	1.9	3.4	3.0	0.50
Toe graph	1.9	2.4	12.7	6.4	9.8	5.1	9.6	6.4	0.59
Height	50.7	3.1	56.6	2.7	61.2	2.6	64.2	3.3	0.86
Weight	61.5	20.0	78.2	18.8	108.7	30.3	117.7	16.2	0.72

The reports of extracurricular activity revealed that 73% of the subjects participated regularly in sports teams. Spearman's correlation analyses between this activity measure and the motor and sensory tasks demonstrated that subjects who played regularly on a sports team, regardless of type of sport, displayed significantly fewer errors on the sensory tasks (absolute rho values ranged between .15 and .36), and had more efficient scores on the motor tasks (absolute rho values ranged between .20 and .39). Analysis of the remaining activity measures (e.g., nintendo time, etc.) revealed no statistically significant associations.

TABLE 2. F-ratios (analysis of variance) for finger and foot tap scores, and for numbers of errors for finger and toe gnosis and graphaesthesia, as a function of the four age groups in Table 1, before and after covariance for height and weight

		Covariate	
Variable	*F-ratio*	*Height*	*Weight*
Finger tap	55.20***	10.34**	25.80**
Foot tap	32.00***	3.22*	11.48**
Finger gnosis	3.87*	0.49	1.31
Toe gnosis	7.53**	2.10	3.58*
Finger graph	9.05***	8.69**	8.95**
Toe graph	14.10***	9.70**	12.02**

*$p < .05$; **$p < .001$; ***$p < .0001$.

Table 3 presents the means and standard deviations for the numbers of foot taps per 10 s and the numbers of errors for toe gnosis and toe graphaesthesia for both right and left limb in ages 7 to 14, separately. This information is provided, in the tradition of Knights and Norwood (1980), for normative use. Analyses of variance within each age group for each task never revealed statistically significant differences between boys and girls; consequently, the scores for the two sexes were pooled.

Zero order correlation (Pearson) coefficients between the various measures for the left and right sides of the body, combined, are shown in Table 4. The bottom diagonal shows that the partial correlation coefficients after the effects of age (yearly integers) were held constant. When the variance associated with age was accommodated, the correlations between the measures were either unchanged (between specific sensory measures), or were no longer statistically significant.

To discern the potential differential development of these tasks, four-way analyses of variance with two levels repeated (left vs.

TABLE 3. Means and standard deviations for foot tap, toe gnosis, and toe graphaesthesia for ages 7–14 years

	7 years (n = 10)		*8 years (n = 11)*		*9 years (n = 9)*		*10 years (n = 17)*	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Foot tap-D	24.2	4.2	29.2	4.8	30.1	7.3	34.6	5.1
Foot tap-ND	21.2	3.1	25.7	5.7	30.7	8.1	31.0	6.0
Toe gnosis-R	6.5	2.3	7.0	3.1	5.3	1.7	5.6	2.3
Toe gnosis-L	8.1	1.9	7.5	3.1	7.0	1.7	6.2	2.2
Toe graph-R	1.6	1.7	1.0	1.2	5.2	2.6	6.8	5.4
Toe graph-L	1.0	1.7	0.5	0.8	6.4	3.8	6.4	3.5
	11 years (n = 7)		*12 years (n = 8)*		*13 years (n = 15)*		*14 years (n = 9)*	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Foot tap-D	36.1	6.3	37.4	7.5	42.4	6.5	43.9	4.5
Foot tap-ND	33.3	5.0	33.3	6.3	38.8	6.8	41.6	6.7
Toe gnosis-R	5.0	1.6	3.6	1.4	4.9	2.4	4.0	1.7
Toe gnosis-L	4.7	1.7	3.1	3.1	5.4	3.5	5.9	3.2
Toe graph-R	5.4	3.2	4.5	2.4	5.3	3.3	3.7	3.7
Toe graph-L	4.4	2.7	5.3	3.5	5.5	4.3	4.0	2.0

TABLE 4. Zero-order correlation (Pearson) coefficients (upper diagonal) and partial correlation coefficients after the effects of age were held constant (lower diagonal) for motor (finger, Fg-T and foot tap, Ft-T) and sensory [finger (F), toe (T) gnosis (Gn), and graphaesthesia (Grph)] tasks.

Variable	*Fg-T*	*Ft-T*	*F-Gn*	*T-Gn*	*F-Grph*	*T-Grph*
Fg-T	1.00	0.70***	–.35**	_.45***	–.26*	–.27*
Ft-T	.19*	1.00	–.35**	–.42***	–.23*	–.22*
F-Gn	–.12	–.14	1.00	.47***	.54***	.41***
T-Gn	–.18*	–.16	.38***	1.00	.46***	.42***
F-Grph	–.03	–.01	.51***	.40***	1.00	.60***
T-Grph	–-.03	.01	.37***	.36**	.54***	1.00

*$p < .05$; **$p < .01$; ***$p < .001$.

right side of the body; foot/toe vs. finger), and two nonrepeated (age, sex) were completed separately for the tapping, gnosis, and graphaesthesia tasks. For tapping performance, there were statistically significant differences in the numbers of responses between ages [$F(3,77) = 62.70$, $p < .001$], limbs (feet vs. fingers) [$F(1,77) = 124.86$, $p < .001$] and right vs. left side of the body [$F(1,77) = 93.81$, $p < .001$]; the index fingers were significantly more agile than the feet, and the right side of the body was significantly more agile than the left.

There was a weak, but, statistically significant [$F(3,77) = 2.93$, $p < .05$] interaction between age and limb. Post hoc analysis indicated that this was due, in large part, to the higher finger tap rates for the 11–12 and 13–14 year-olds, relative to the 9–10 year-olds; the 13–14 year-olds displayed significantly faster foot tapping rates than the 11–12 year-olds only. None of the other interactions was statistically significant. A four way analysis of variance (two levels repeated) for the numbers of gnosis errors also showed the significant age differences [$F(3,76) = 7.87$, $p < .001$], finger vs. toe differences [$F(1,76) = 445.13$, $p < .001$] and left vs. right asymmetry [$F(1,76) = 7.49$, $p < .001$]. Again, the latter two differences were reflected in the greater numbers of gnosis errors for the toes, relative to the fingers, and the greater number of errors for the left side of the body compared to the right.

There were two statistically significant interactions. The first involved an age by limb interaction [$F(3,76) = 4.07$, $p < .05$]. The

major source of the interaction was due to the 11–12 year-olds who displayed fewer errors for toe gnosis relative to the 7–8 and 9–10 year-olds while this differential age effect was not noted for finger gnosis. The second involved a sex by side interaction [$F(1,76) = 4.92$, $p < .05$]. Post hoc analyses indicated that the girls exhibited significantly more errors for the left side of the body (equivalent to about 2 errors for both toes and fingers combined) compared to the right side of the body, while the boys did not display this asymmetry. There were no other statistically significant interactions.

The four-way analysis of variance (two levels repeated) for graphaesthesia was completed with only three groups (7–8 year-olds not included because of the required use of Xs and Os). Significant age differences [$F(2,59) = 3.45$, $p < .05$] and finger vs. toe differences [$F(1,59) = 103.47$, $p < .001$] were apparent. This limb effect was reflected in the greater number of errors for the toes compared to the fingers. There were no significant sex or left-right body side differences. None of the interactions was statistically significant. Covariance for height, analyses of only right-handed subjects, or analyses by age in yearly integers (versus age groups) did not alter the effects.

DISCUSSION

Qualitative inferences with respect to the integrity and ontogenesis of the medial surface of the cerebral hemispheres have relied upon gross inspections of either motor agility or sensory thresholds of the toes or feet. Nominal construct validity for these inferences has been supported by either the consequences of stroke or gross interventions by electrical stimulation (Penfield & Rasmussen, 1950) in adults. Whereas the rostral medial surfaces of the cerebral hemispheres (usually immediately above the anterior cingulate and ventrorostral to the supplementary motor area) are involved with foot agility, the more caudal paracentral lobules are associated with sensory representation of the toes and feet. Ischemic accidents that involve the anterior cerebral artery are well known to be associated with deficits in motor and sensory ability of the legs and feet (Reitan & Wolfson, 1985).

The purpose of the present study was to obtain normative data, as well as to determine the relative ontogenetic patterns for motor agility of the feet and fingers, recognition (gnosis) of the toes and fingers, and graphaesthesia for the toes and fingers in a population of normal children. This work was a component of the search for performance-based measures, by which we can infer the metabolic (functional) activity within cerebral regions that have been ignored or under-emphasized. Peters (1990) has also considered the potential utility of quantitative assessment of the lower limbs within neuropsychological contexts.

The results indicated that the upper distal limbs exhibited greater agility, finer graphaesthetic accuracy, and fewer gnosis errors than did the lower distal limbs. However, the discrepancy between the feet and the hands for motor agility was relatively smaller than for the perceptual tasks of the gnosis or graphaesthesia. In light of the differential sensory input and representation for the fingers with respect to the toes in the homunculus (Kandel, Schwartz, & Jessell, 1991), the discrepancy between fingers and toes is expected.

There was strong evidence of asymmetry between both motor and sensory tasks and left and right sides of the body. The differential development (inferred by numbers for errors or events per unit time) of the left and right hemispheres was less apparent in the motor tasks than in the sensory tasks. Considering the differential development of the right and left hemispheres (Spreen & Strauss, 1991), the lower speed and less accuracy for the left limbs, relative to the right limbs, were predictable. A calculation of the proportion of the difference between the limbs based on the means for each measure, indicated that the left limb was approximately 5% to 10% less accurate for toe gnosis, finger gnosis, toe graphaesthesia, finger graphaesthesia, finger agility, and foot agility. These values were all within the range of the expected asymmetry between the dominant and nondominant limb (Reitan & Wolfson, 1985; Spreen & Strauss, 1991).

The major interaction between age and limbs (feet vs. hands) occurred for gnosis of the digits. The results of this analysis indicated that where there was no substantial improvement between the ages of 7–14 for finger gnosis, there was a significant change in accuracy for toe gnosis as a function of age. The major change

occurred between the 9–10 year-olds and the 11–12 year-olds. Comparable changes were not found for either graphaesthesia or agility for the right or left limbs.

This inflection point in the accuracy for naming the toes correctly between the ages of 9–10 and 11–12, compared to the corresponding tasks for the fingers, suggests that a sudden maturational change may take place in the paracentral lobule at approximately that time. This would suggest that the maturation of the paracentral lobule, which is serviced primarily by the most distal branches of the ACA, is relatively delayed compared to the anterior surface (motor neurons for foot agility) and the lateral cerebral hemispheres (finger gnosis and agility).

A similar inflection, or non-linear change, in accuracy between the age groups of 9–10 years and 11–12 years of age has been found recently (Moulden & Persinger, 2000) for the left ear, but not the right ear (Saxby & Bryden, 1984), during the dichotic word listening task that was developed by Richard Roberts and colleagues (1994). Because the left ear detection during dichotic word listening reflects maturation of the corpus callosum, and a significant portion of the caudal branch of the ACA (the callosomarginal artery) also services the paracentral lobule (Carpenter & Sutin, 1983), the shared inflection in maturational capacity for both toe recognition and left ear processing supports the hypothesis that the area most distally supplied by the ACA is relatively delayed along the continuum of development.

The effect of sizes of sex differences are usually too small in magnitude to be discriminated statistically, unless the sample size is quite large or the task is gender conspicuous. Consequently, we did not expect obvious sex differences for the tasks that were employed in this study. However, there was one significant interaction between gender and body symmetry for identification of the toes. Post hoc analyses indicated that although there was no discrepancy between the left and right side of the body for this measure for the males, there was a significant discrepancy between the left and right side of the body for the females. The toe gnosis for the left foot was significantly worse than the right foot for females. This asymmetry could suggest that females display a significant delay in the maturation of the right paracentral lobule compared to males.

As might be expected, in any collection of measures where a powerful ontogenetic variable is operative, the motor and sensory measures were significantly correlated with each other. After age was covaried, the statistically significant correlations between the motor and sensory tasks were eliminated. However, the sensory measures, gnosis and graphaesthesia, remained positively correlated.

One final interesting observation was the relative robustness of the age effect for the improvement of agility, gnosis, and graphaesthesia for both limbs. This was not affected appreciably by covarying for body weight. Covarying first for height, however, significantly removed the effect of age upon foot agility, as well as toe gnosis. Our subjects were within the age interval when a maximum growth in leg length is present. Espenchade and Eckert (1980) have reported that the amount of mass and the total growth of the legs are significantly greater than that of the arms and hands during this time. If height and changes in height are strongly related to foot agility and toe gnosis (i.e., the capacity to identify one's toes), then the transient difficulties with coordination for the lower limbs ("clumsiness") that have been popularly associated with children in this particular age range (Losse et. al., 1991; Dare & Gordon, 1970) might be explained.

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